The Cold Spot in the light of PLANCK

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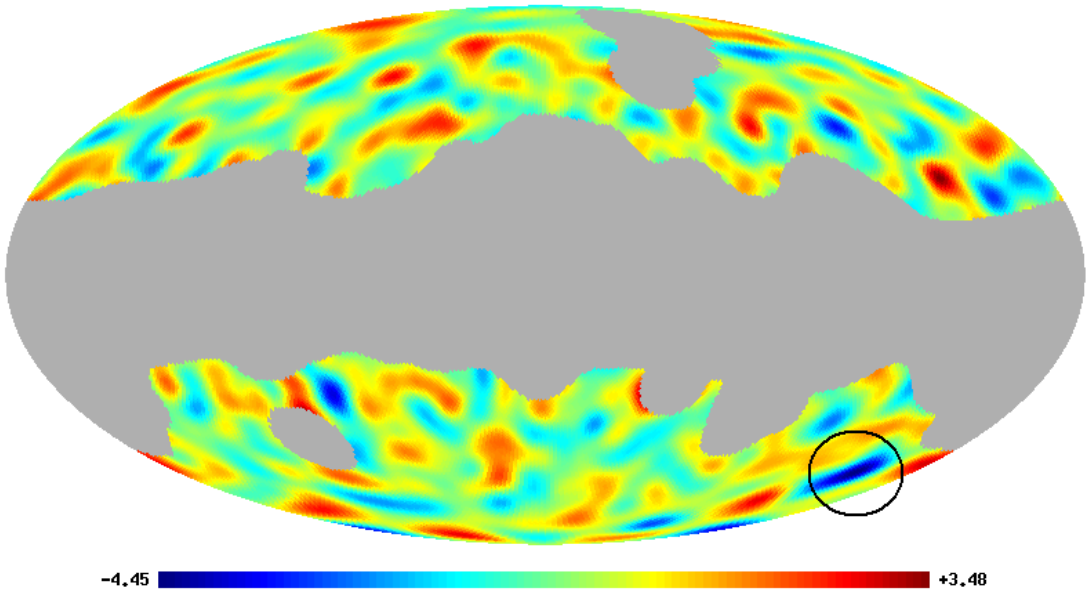
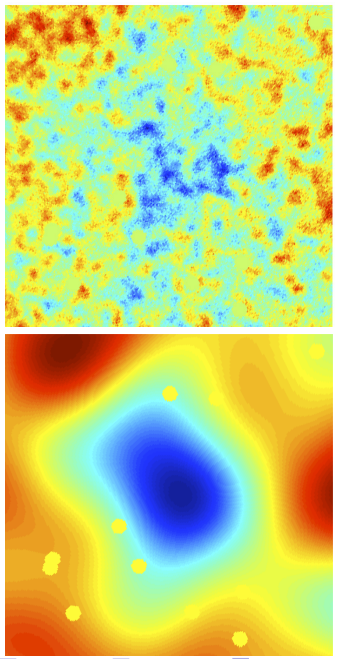
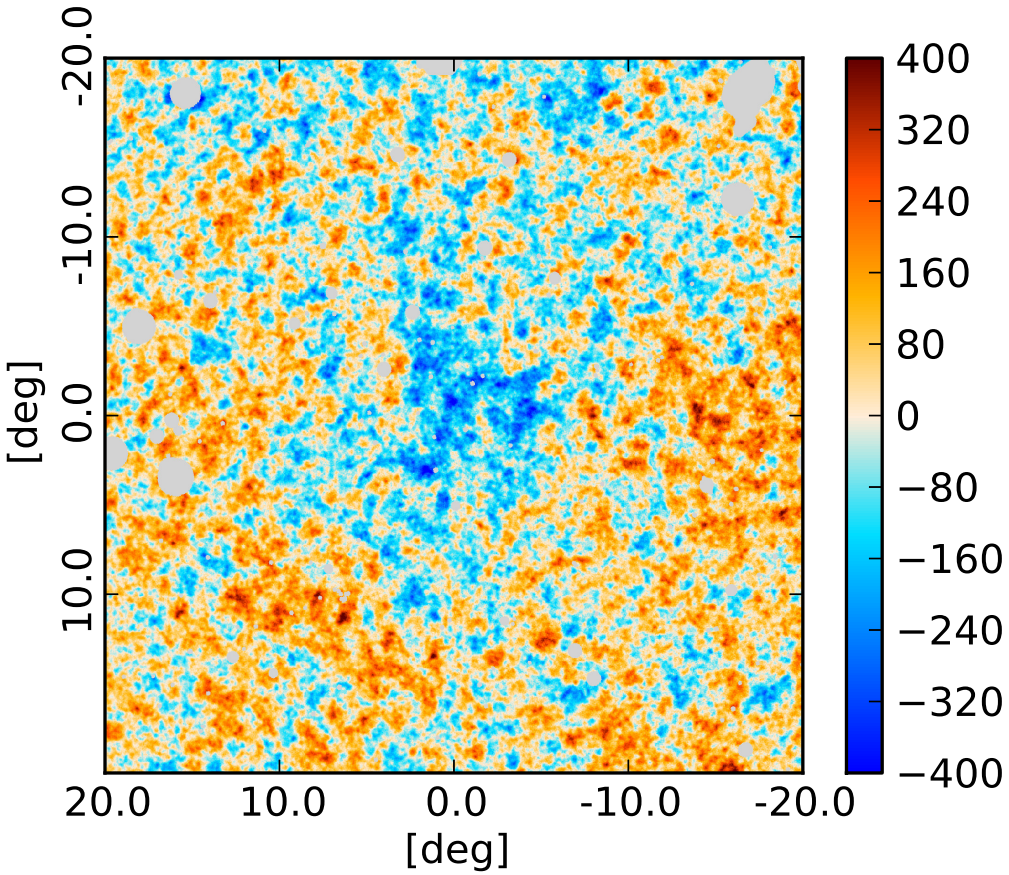
The Cold Spot detection

- Detected by Vielva et al. (2004) at scales $\sim 10^{\circ}$ in the sky using the kurtosis estimation in the SMHW coefficients.
- It is rare in the context of the ΛCDM: $\sim 1\%$ looking at the area (Cruz et al., 2005).





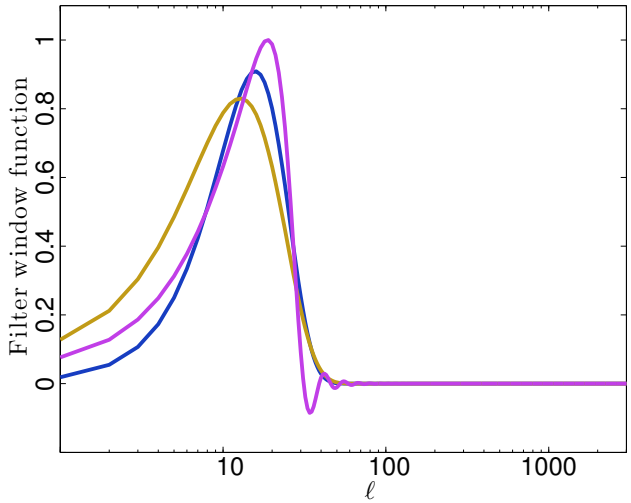
The Cold Spot seen by PLANCK

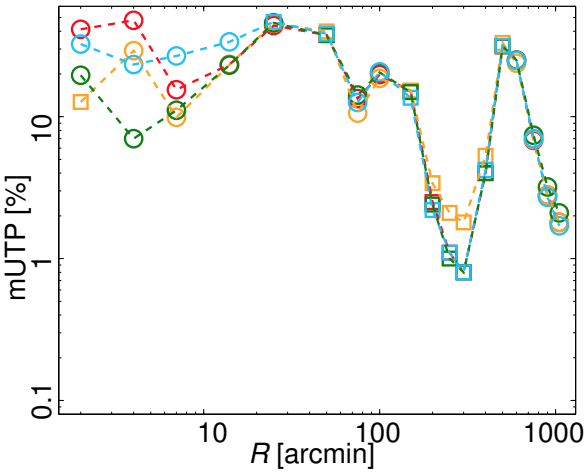


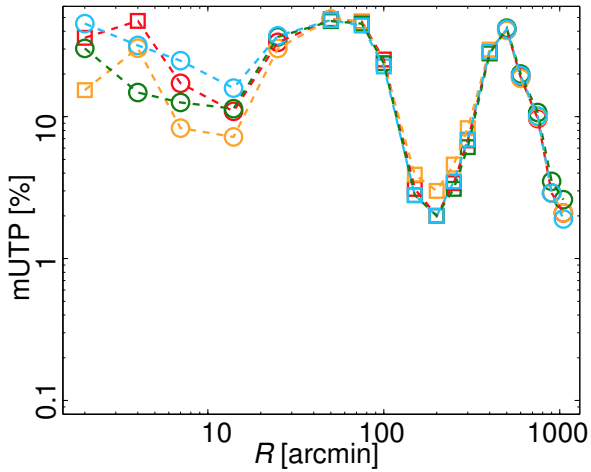
- Confirmed anomaly.
- Cold Spot analyses:
  - Excess of kurtosis.
  - Area.
  - Mean angular profile.

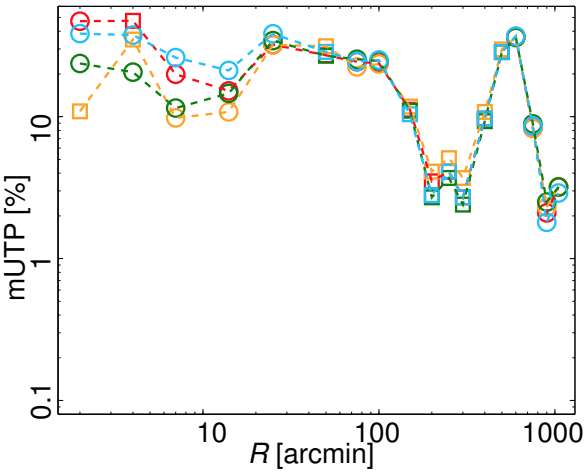
Multiscale analysis

- 18 scales selected using the SMHW (blue), GAUSS (yellow) and Savitzky-Golay (magenta) kernels.
- Excess of kurtosis at the Cold Spot scale.





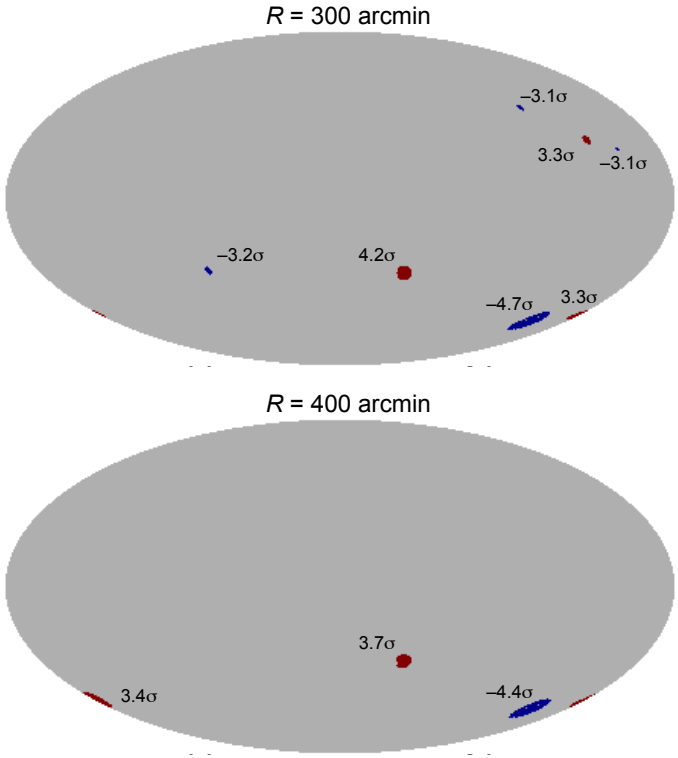




Area

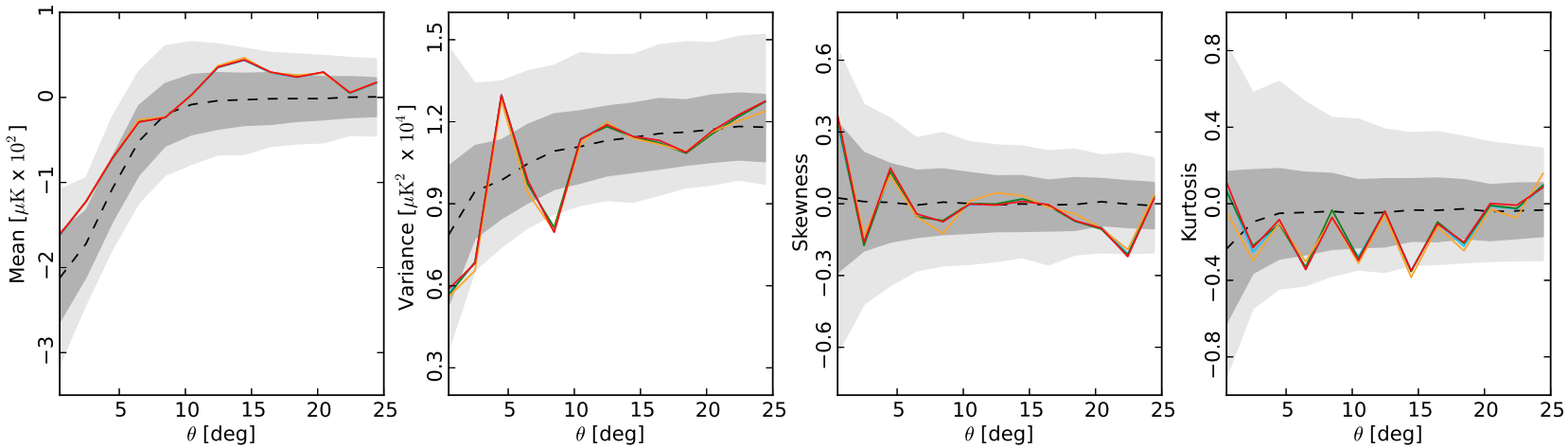
- Area above a given threshold, as a function of the SMHW scale: anomalously cold area on scales $\sim 10^{\circ}$.

Area	Scale [arcmin]	Probability [%] Comm.	NILC	SEVEM	SMICA
		SMHW			
Cold	200	3.8	5.1	3.7	3.8
	250	1.4	2.4	1.4	1.4
	300	0.4	1.5	0.4	0.4
	400	0.9	0.9	0.9	0.9
Hot	200	2.0	2.6	1.7	1.5
	250	2.4	3.0	2.1	2.0
	300	4.2	5.0	4.1	3.9
	400	...	...	...	...



Local properties

- The background: Zhao, 2013.
  - Inconsistencies with respect to the Gaussian hypothesis.
  - Local statistics: mean, variance, skewness and kurtosis.
- Planck analysis:
  - Statistics computed within 13 concentric rings spaced in steps of $\sim 2^\circ$.
  - Simulations with a cold spot, at least, as intense as the Cold Spot from the data in the SMHW coefficients at $R = 300'$.



Probabilities

Probabilities of obtaining values for the χ^2 statistic of the angular profiles larger than those determined from the data.

Angular profiles	Probability [%]			
	Comm.	NILC	SEVEM	SMICA
Mean	0.9	0.8	1.0	0.9
Variance	40.0	40.0	38.0	42.0
Skewness	79.0	82.0	85.0	80.0
Kurtosis	75.0	56.0	75.0	77.0

$\Rightarrow$ Only the mean value should be considered anomalous.

Forecast for polarization

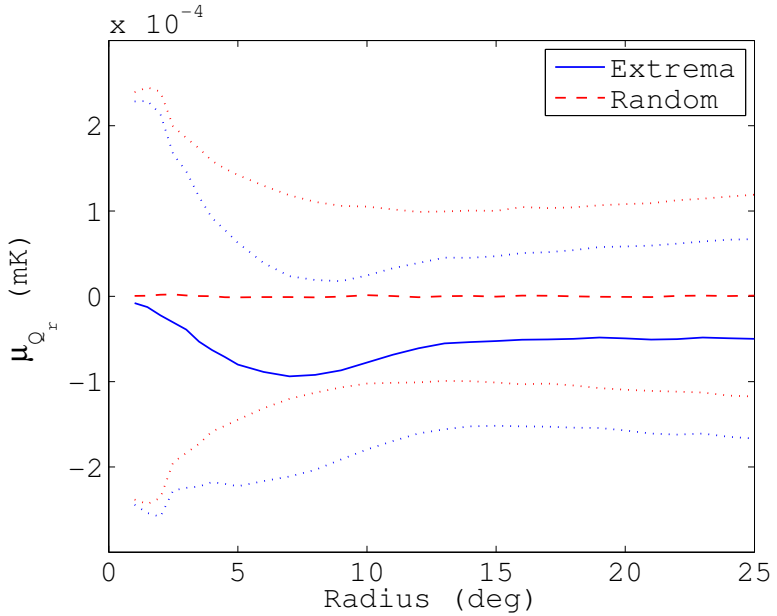
- What would the polarization offer to the understanding of the Cold Spot?
  - Gaussian peak: counterpart in polarization predicted by $\Lambda\mathrm{CDM}$. (H_0)
  - Product of the gravitational evolution of a secondary anisotropy: no expected pattern in polarization. (H_1)
- We employ an estimator which explores the TE cross-correlation.

Forecast for polarization

Q_r and U_r Stokes parameters:

$$Q_r(\theta) = -Q(\theta)\cos(2\phi) - U(\theta)\sin(2\phi)$$
$$U_r(\theta) = Q(\theta)\sin(2\phi) - U(\theta)\cos(2\phi)$$

- Ideal case: noise-free experiment.



Fisher discriminant

- The information of each hypothesis is represented by

$$\xi_{\mathrm{H}_0}(i) \equiv \mu_{Q_\mathrm{r}}(\mathbf{x}_{\mathrm{ext}}, \theta_i)$$
$$\xi_{\mathrm{H}_1}(i) \equiv \mu_{Q_\mathrm{r}}(\mathbf{x}_{\mathrm{rnd}}, \theta_i)$$

- $\bar{\xi}_{\mathrm{H}_\gamma}$ and $\mathbf{C}_{\mathrm{H}_\gamma}$ are computed with 10^4 simulations ($\gamma = \{0,\ 1\}$).
- Two sets of 1000 (representing each hypothesis, respectively) Fisher discriminant values τ_γ are computed combining information of both hypotheses:

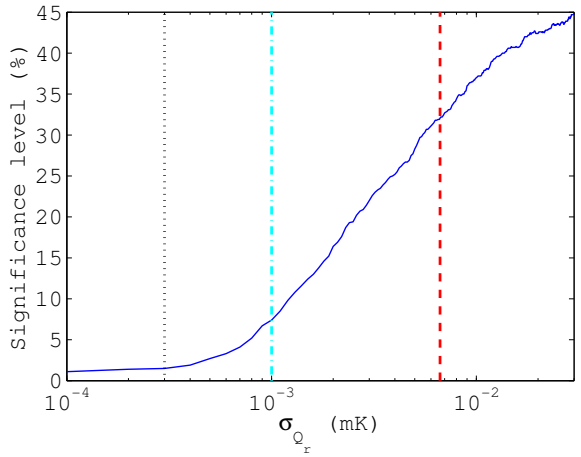
$$\begin{aligned} \tau_{\mathrm{H}_0} &= \left(\bar{\boldsymbol{\xi}}_{\mathrm{H}_0} - \bar{\boldsymbol{\xi}}_{\mathrm{H}_1}\right)^t \mathbf{C}_{\mathrm{tot}}^{-1} \boldsymbol{\xi}_{\mathrm{H}_0} \\ \tau_{\mathrm{H}_1} &= \left(\bar{\boldsymbol{\xi}}_{\mathrm{H}_0} - \bar{\boldsymbol{\xi}}_{\mathrm{H}_1}\right)^t \mathbf{C}_{\mathrm{tot}}^{-1} \boldsymbol{\xi}_{\mathrm{H}_1}, \end{aligned}$$

  with $\mathbf{C}_{\mathrm{tot}} = \mathbf{C}_{\mathrm{H}_0} + \mathbf{C}_{\mathrm{H}_1}$.
- Discrimination power between the two hypotheses: the fraction of the τ_{H_1} values that are greater than the median value of the τ_{H_0} distribution.

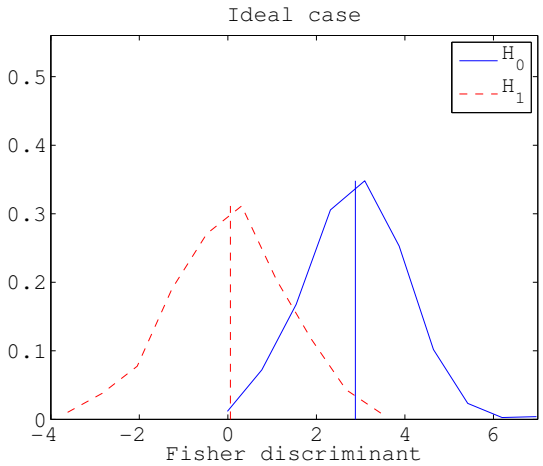
Forecast for polarization

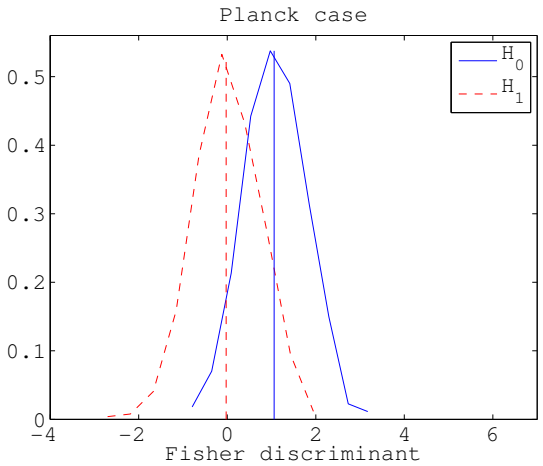
- Two different cases:
  - Noise-free case.
  - Noise level as expected in PLANCK ($\sigma_{\rm pol} \approx 1 \mu{\rm K}$)

Fernández-Cobos et al., 2013



1.0%





$\sim 8\%$

Planck is a project of the European Space Agency, with instruments provided by two scientific Consortia funded by ESA member states (in particular the lead countries: France and Italy) with contributions from NASA (USA), and telescope reflectors provided in a collaboration between ESA and a scientific Consortium led and funded by Denmark.